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Impacts of Rapid Population Growth, Urbanization and Climate Change on Water Security Risks in Pakistan's Down Stream Areas

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ABSTRACT

Water shortage has become the most significant type of non-traditional security that is facing Pakistan especially in the downstream areas of Indus River Basin. This study discussed how current population growth, increasing urbanization, and climate change convergence compound water scarcity and its socioeconomic and environmental impacts. The study conducted using a qualitative research methodology, in which the close nexus of effects of demographic pressure and increase in water demand, inefficient water governance, hydrological variability, and climate-induced alterations in the Indus River System are analyzed by extensively reviewing and examining academic literature, government reports, policy reports, and other international publications. The results indicate that population growth has largely decreased the availability of water per capita, as well as urbanization and industrialization have raised domestic, agricultural, and industrial water demand. The effects of climate change have also interfered with the hydrological cycle by causing a receding of glaciers, unpredictable monsoon cycles, recurrent floods, extended droughts, and rising of the sea level leading to reduced water quality and quantity in down-stream regions. The paper concludes that water crisis in Pakistan is a compilation of the interaction of the three factors of demographic, environmental, and governance factors rather than being a one-factor cause. It highlights the urgency of integrated water resources management, climate-resistant infrastructure, institutional reforms, equitable water distribution, demand-side management, sustainable population policies to enhance the Pakistan long-term water security and socioeconomic resilience.

Keywords: Water Scarcity, Indus River Basin, Population Growth, Urbanization, Climate Change, Water Security, Hydrological Variability, Food Security, Downstream Regions.

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Introduction

The study lays the groundwork for comprehending the water scarcity risks arising as a result of the convergence of rapid population growth, accelerating urbanization and climate change in the Pakistani downstream. In the past two decades, Pakistan has been among the top 10 countries in the world that are most vulnerable to climate change and has lost 10,000 lives due to climate change disasters and incurred \$4 billion in financial damages as a result of 173 catastrophic weather occurrences (Maqbool, 2022). Pakistan is already considered as a water stressed nation, and in the last couple of decades' per capita water availability has significantly reduced. This is especially problematic in downstream areas of the IRS where the population is on a high reliance on reliable river flows for farming, domestic use and livelihoods. A rise in water use anywhere upstream always leads to a decrease in water quality and quantity downstream, whether caused by population growth or agricultural or urban development (Maqbool, 2022). Some other issues such as inequitable distribution of water are also a great problem along with other challenges of water management in 21st century for Pakistan including population pressure, fast urbanization and industrialization Pakistan's water management is facing significant challenges in the twenty-first century due to a number of other difficulties, such as unequal water distribution, population burden, increasing urbanization, and growing industries (Khan, 2019). Increased water demand, due to rapid population growth, for food production, drinking water and industrial use, has put a huge strain on water resources which are scarce. Meanwhile the traditional water use pattern is changing in urban areas.

As a result of the expansion of cities in the downstream regions, the use of municipal and industrial water, the extraction of groundwater, and the discharge of untreated sewage, industrial effluents, and water pollution have all risen. Report of UN that as for fifty percent population of the world lives in cities and it is projected this number will reach 67% in 2025 (Khan, 2019). The effects of these factors are not only water supply shortages but also the deterioration in water quality, resulting in less usable water for human and agricultural purposes. These challenges are further compounded by climate changes that affect water cycles. Lack of

adequate storage capacity for water in Pakistan and poorly managed dams and reservoirs add to the complexity of water resources utilization in the country, and further aggravate the contamination problem due to inadequacy of suitable wastewater treatment infrastructure. The ever increasing world population from 6.7 billion to more than 9.0 billion by 2050 cannot be met by current agricultural production systems (Hussain et al., 2019). The flow regime of Indus river has been modified by the effects of rising temperature, changes in precipitation, more frequent flooding and droughts, variability in glacial melt, and sea-level rise. The paper emphasizes the multidimensional character of water scarcity by highlighting these mutual linkages and demonstrates the necessity to adopt an integrated water management and policy approach that considers vulnerabilities of the end users. Global cooperation is required to address water related issues like scarcity, pollution and climate change (Ahmad, et al., 2023). The impacts of these problems are far-reaching in society, and among various industries. The agricultural sector, which serves as the foundation of Pakistan economy, is experiencing major challenges due to decreased crop yields and productivity, ultimately resulting in food insecurity. These modifications have implications for downstream locations in terms of variable water supply, salt water intrusion, and exposure of ecosystem services and livelihoods.

Literature Review

Shirsat *et al.* (2026) in this paper "Past, Present and Future of the Indus Water Treaty: Implications for Transboundary Water Governance Challenges and Modernization Prospects" narrated the historical context, current issues and future outlook of the Indus Waters treaty (IWT) within the water governance in transboundaries between India and Pakistan. The authors contended that, though the treaty has upheld massive water wars over the past sixty years, it was now under mounting pressure with climate change, population explosion, urbanization, rising water demand and geo-political spats. The paper also concluded that the Chenab and Ravi rivers are the most at risk to water stress due to their strategic location as well as due to the clustering of water infrastructure projects, but that the Jhelum and Sutlej rivers have other governance and resource management issues. Instead of being confined to a single treaty as the cause of disputes, the authors argue that other political tensions

between India and Pakistan have made implementing it difficult and made any bilateral cooperation unlikely (Shirsat *et al.*, 2026). The study gave limited attention to the socioeconomic impacts of water insecurity on Pakistan's downstream communities, particularly in Sindh and the Indus Delta.

Safia Mansoor in the article “Pakistan’s Water Security Crisis: Challenges and the Case for Integrated Water Resource Management” explained the developing water security crisis in Pakistan through a social, technological, economic, environmental, political, legal, and ethical (STEEPLE) analysis contributing to water shortage. It claimed that the increased population growth rates, urbanization, climate change, ineffective governance, decreased water consumption and the loss of water underlying the ground, deteriorating water quality and the like, have all contributed to a higher water insecurity in the nation. The author highlighted that the problem of climate change has also enhanced the rate of floods, droughts, and unpredictable rainfall that have diminished the predictability of the water resources of Pakistan. The article was concluding that no integrated and coordinated policy approach could be beyond what was required to ensure sustainable water security in Pakistan balancing both environmental and socioeconomic development (Mansoor, 2025). There is lack of empirical field-based evidence on how local communities are affected by water scarcity and climate change, creating opportunities for more localized and community-focused research.

Kamran *et al.* (2024) in this paper “Assessing the impact of socio-demographic factors on municipal water security in planned and unplanned urban centers of Pakistan” addressed that the contribution of socio-demographic aspects to municipal water security in Pakistan compared the planned and unplanned urban areas such as Islamabad, Rawalpindi and Mardan. The paper has postulated that the fast rate of population expansion, urbanization in an unplanned manner, and global warming have exerted a lot of strain on the available water resources in the country, and they thus tend to create a rising water crisis. The research shows that the fast historical growth and population growth have significantly augmented the level of water demand and the current infrastructure has not been able to

support the increasing demands of urban dwellers. The authors determined that the IM within cities, better governance, water infrastructure investment, groundwater conservation initiatives, and popular education are needed to achieve sustainable water security in Pakistan (Kamran *et al.*, 2024). This study provided limited analysis of how transboundary water governance and the Indus Waters Treaty interact with population growth, urbanization, and climate change to influence downstream water security.

Nazam Maqbool in the article “Impact of Climate Change on Water in Pakistan” discussed the effects of climate change on the Pakistan water resources and said that climate change has emerged as one of the greatest challenges of water security in this nation. The research revealed that increased temperatures, shifting precipitation patterns, accelerated melting of the glaciers, frequent floods, extended droughts, and decreased recharge of groundwater are changing the quantity and quality of water in Pakistan. Being a water stressed nation, which heavily depended on the Indus River system, Pakistan is most vulnerable to these climatic changes, which will affect agricultural production, food security, energy production, and social economic development. The author has also highlighted that the rising water demand, poor capacity of water storage, water management systems and poor governance add to the negative impact of the climate change. The research proposed to have enhanced integrated water resources management, augmented water storage facilities, efficient irrigation, increased climate adaptation plans, and enhanced regional cooperation, as a way of securing the long-term water security, as well as suppressing future water-related hazards in Pakistan (Maqbool, 2023). The study provided a broad overview of climate change and water resources in Pakistan but did not specifically examine its impacts on the downstream areas of the Indus Basin.

Sohail *et al.* (2023) explored how rapid urbanization, land use and land cover (LULC) change, land surface temperature (LST) and the Normalized Difference Vegetation Index (NDVI) influence groundwater depletion in Islamabad, Pakistan. The study, based on remote sensing, GIS methods, groundwater data, and meteorological data between 2000 and 2020, discovered that the high rate of population growth and urbanization has

led to a high water demand, leading to overuse of the groundwater in terms of drawdown and a steady drop in the level of the actual water table. Replacement of vegetation and open land with built-up areas has decreased ground water recharge, and increased pressure on fresh water resources. Authors also underscored that the water crisis has been fueled by climate change and the lack of effective management of water. As a way of supporting mitigation to these challenges, they advocated for the application of sustainable urban planning, check dams and artificial recharge system, protective use of green space, and reinforcement of water management policies to make sure the sustainability of the groundwater in Pakistan is effective in the long term (Sohail *et al.*, 2023). The study focused on groundwater depletion in Islamabad and does not assess the impacts of rapid urbanization and climate change on water security in Pakistan's downstream regions, particularly the Lower Indus Basin.

Water Scarcity in Pakistan

Water scarcity is one of the most pressing issues in Pakistan today, causing major challenges in the country's economic, food and social development. Water scarcity is a big issue in Pakistan, in which 79% of drinking water is contaminated. In the current period of unparalleled urbanization, pressure from population and industrial growth poses a major danger to Pakistan's water management (Jabeen *et al.*, 2015). In the last few decades however, the country has gone from water abundance to water stress and is now near water scarcity. One of the most serious signs of this crisis is a significant drop in the availability of water per person. The population growth has seriously reduced the water availability per capita and has brought Pakistan below the internationally recognized water stress levels. The main sources of water in Pakistan are precipitation and snow fall which are transformed into glaciers in the country, and country's long river system, large and small water lakes, coastal basins. 89% of the rural and 96% of urban population in Pakistan is suffering with Hydro contamination. Only one percent of the factory wastage is treated before its discharge in Pakistan and the wastewater is being discharged straight into the rivers (Awan *et al.*, 2016). With population growth continuing unabated, demand for water for domestic needs, agriculture and industry has risen and water resources have not changed

significantly overall. Agriculture consumes the most water in Pakistan and extremely demands surface and ground water resources. In addition, water wastage in canals, inefficient irrigation and irrigation of water-intensive crops have exacerbated water scarcity.

The problem of water in Pakistan is one of the lowest in the world with 908 cubic meters of water per citizen, below the scarcity threshold of 1005 meters per capita. According to the report, Pakistan's water security crisis will deteriorate in the absence of institutional reforms, equitable water distribution, and long-term conservation strategies, jeopardizing long-term socioeconomic stability (Begum & Ali, 2025). In the meantime, there has been a significant increase in groundwater abstraction, which has led to a decrease in water quality and levels in many places. The crisis has also been fueled by inadequate water governance and management. Unequal access to clean water is deepening existing socioeconomic disparities and holds the potential to catalyze civil unrest amid macroeconomic instability (Sattar, 2023). The lack of institutional coordination, outmoded infrastructure, unequal allocation among provinces and the ineffective implementation of water policies has restricted the sustainable management of water resources in Pakistan. Recent increasing and unpredictable rainfall across the country has caused dire floods in urban areas, which is a clear-cut effect of Climate Change, and Pakistan is now facing the challenge. The country's larger cities were hit by record levels of rain in 2024 and 2025, causing the destruction of vulnerable drainage systems and displacing thousands. At least 242 people have already been lost to life in the latest wave of flooding in 2025, and even more people are expected to lose their lives with the upcoming fresh flooding (Mahmood & Khalid, 2025). Such governance problems are especially impacting downstream areas where releases from upstream areas are required for water supply. Changes in rainfall, higher temperatures, and more variability in river flows have exacerbated vulnerabilities already present in the region due to climate change.

The frequency and severity of droughts and floods have impacted water availability, and long-term uncertainty has been caused by glacial melt in the upper Indus Basin. Sea-level rise has also contributed to the loss of freshwater in coastal regions, resulting in salt water intrusion. Since

1995, over 832,000 people have died and direct economic losses of nearly USD 4.5 trillion have been reported attributable to over 9,700 extreme weather events. The number and severity of climate-related crisis events are increasing and these statistics highlight the need for climate action (Climate Risk Index , 2026). This background serves to emphasize the issue of water scarcity as a national concern and provides the background for a discussion of the increased effects of water scarcity on the downstream regions of Pakistan. At the same time, global warming has tipped the melting of glaciers in the Hindu Kush–Himalayan region, which contributes more than 75pc of the Indus River's flow, up a notch. These trends could have a destabilizing impact on the timing and volume of the river water that Pakistan has depended on for thousands of years. In the near future, the World Bank Climate Change Knowledge Portal (CCKP) predicted an increase in the average temperature of 4.9°C in Pakistan by 2090, and in the future, it is expected to become more and more hydrological volatile (Climate Risk Index , 2026). Overall, water scarcity in Pakistan is the consequence of the interplay of a variety of factors, including demographic pressures, inefficient water use, governance failures and climate-induced stress.

Rapid Population Growth and Increasing Water Demand

The swift increase in population is a significant contributor to the escalating demand for water in Pakistan, placing immense strain on the country's limited water resources. Pakistan's population has grown at a much higher rate than water supply, causing the per capita water availability to decrease since the country's independence. Despite minor improvement in water security in terms of quality and quantity in the last 12 years, Pakistan is still facing water insecurity as over 80 per cent of its population is still not accessing clean drinking water due to implementation gaps (Kiani, 2025). The total amount of renewable water has not changed, but the demand for domestic, agricultural and industrial uses has been greatly increased due to the growth of the population, leading to a high level of water stress in this country. Domestic water consumption has increased considerably due to several factors such as population growth and corresponding requirements for potable, sanitary and water for domestic purposes.

Water crisis is one of serious problems in Pakistan. The country is fast transitioning from water stressed country to water scarce country and once the country's annual water per capita becomes less than 1,000 m³ per capita, it is very likely some of these annual water availability has already been reached. That would equate to a person in Pakistan receiving the water of a swimming pool that's half the size of an Olympic swimming pool each year (Parry et al., 2024). Very high demands on Urban and Urban space areas are due to the population density and development of Informal Settlement in towns. This heightened demand puts pressure on the existing water supply and distribution system, leading to regular water shortages, unequal access, increasing reliance on secondary sources of water, such as private tankers and groundwater pumps which are unsafe and expensive. Agriculture is still using the most water in Pakistan, comprising the vast majority of freshwater withdrawals. But Water to Pakistan, since 80 percent of the agricultural areas are irrigated using water from Indus and its tributaries (Raazia & Munir, 2022). A sharp decline in per capita water availability of more than 70% over the last 70 years and increasing water scarcity fueled by population growth, climate change, poor management and geopolitical tensions are the major drivers of the worsening water crisis in Pakistan, which is expected to further deteriorate by 2040. Falling per capita water supply, limited storage and high use of unmanaged groundwater for industrial purposes limit economic water security (Kiani, 2025).

This means that low flow conditions often occur in the canals for the users at the end of the canal in dry seasons. Further, the demand for industrial water has increased with the increase in population and economic growth. Competition between industries is escalating due to their need for water for processing, cooling and pollution control. In many cases, industrial water use is in addition to domestic and agricultural water use, making water scarcer and polluted in downstream water bodies. In addition to engineering interventions like dams, barrages, and storage facilities that completely disregard bilateral agreements between different states, the problems in the water sector are mostly related to conflicts and challenges resulting from the unequal flow distribution of transboundary rivers (Khan, 2023). In general, high population growth rate worsens water scarcity not only through

a greater demand for water but also by causing greater competition for water resources. The effects are most pronounced in the downstream regions of Pakistan where a reliance on the flows coming from the upstream region, poor infrastructure and low adaptive capacity increases vulnerability. Population demand-driven water demand will continue to aggravate the water scarcity risks in Pakistan without effective population planning, demand management and strengthening of water governance.

Population Growth Rates and Regional Distribution

According to Pakistan's most recent demographic data from the 2023 Population and Housing Census, the overall population growth rate in Pakistan is 2.55 percent per year, the highest in South Asia and the world with only 27 countries having higher growth rates (Haider, 2024). The age pyramid and population distribution by age group shows that in Pakistan the proportion of the young population is the highest which if trained with quality education and new skills can play a crucial role in development and prosperity of the country. Rural population is 61.12% and urban population is 39%. The proportion of urban population shows opposite pattern in KP (15%) with Sindh (54%) being the highest, followed by Baluchistan (31%) and Punjab (52%). In Pakistan, the total foreign nationals (FNs) population is 2.12 million, of which Afghan nationals are the highest percentage (90.47%) and majorly reside in KP (Mustafa, 2025). As compared to regional distribution, the census data shows that Punjab is still the most dominant region with over 127 million residents in Pakistan, representing over 50% of its total population. Sindh ranks second to the most populous region with almost 56 million people followed by that of KP with nearly 40.9 million people and the population of Baluchistan is nearly 14.9 million (Pakistani Census, 2023). Meanwhile, the growth rate in KP's population has been lower than the other states and territories, indicating a change in birth and/or migration rates potentially quite different from the national average. The disparities in these regions have significant implications for resource allocation, infrastructure planning, education, health, and political representation as Pakistan continues to change demographically.

Population Pressure in Downstream Provinces

The present population pressure is very high in the downstream provinces of Pakistan like Sindh, where the population is growing rapidly, exceeding the availability of resources, infrastructure, and services. The population of Sindh has also increased rapidly to cross the 55 million mark due to high birth rates as well as inflow of migrant population from other part of the country. Sindh Chief Minister Syed Murad Ali Shah on Monday said the 2023 digital census shows a national population surge, with an annual growth rate of 2.55 per cent, which brings Pakistan's population to 241 million, with Sindh's surpassing 55 million (The News International, 2024). This population explosion puts increased demands on the province's scarce resources, including employment, medical care, education, shelter and food. This population pressure is manifested in various sectors. The thousands of births that happen daily add up to a possible population of almost 96 million, which puts additional pressure on essentials like water, health, food and infrastructure. If effective population control measures are not implemented and sufficient planning is not done, then government capacity to provide essentials may fall way behind the demand (The Nation, 2025). In addition to the provision of services, issues such as environmental sustainability and resource depletion are related to growth in the downstream population. This demographic load is borne by urban centers in downstream regions especially in Karachi.

The population growth and inflow are accelerating faster than the development of infrastructure, resulting in problems that include lack of housing, sanitation overloading, and transportation congestion. Any nation's progress and prosperity are significantly impacted by population increase. Pakistan, like many other nations, is experiencing rapid population expansion, which negatively affects a number of socioeconomic variables, including urbanization, unemployment, poverty, and the availability of healthcare and educational resources (Hijazi, 2025). The population growth is a key driver of unplanned urbanization, with population surges highlighting the strain on basic urban needs. Population growth makes the demand for water higher, which puts extra pressure on the Indus River system, particularly if it coincides with dry spells in the year when less water is available on a per capita basis. Increasing demand for limited

freshwater sources downstream leads to greater competition for water use between agriculture, industry and households, and shows that population pressure also applies to the limits of water resources in the environment (Desk, 2024). In general, population pressure in the downstream provinces such as Sindh is a reflection of the overall trend of population growth in Pakistan, which is characterized by high growth rates in urban, fertile provinces, resulting in high resource demand, high pressure for policy responses and growing challenges in planning sustainable development from social, economic and environmental angles.

Impact on Water Availability

One of the most pressing environmental and development challenges in Pakistan is due to rapid population growth, which is reducing water availability per person. The available renewable water has also significantly reduced per capita in the country over the years due to an increase in population from approximately 34 million in 1951 to more than 240 million in recent years. This reduction is an important one for global comparisons as water stressed is defined as less than 1700 cubic meters per person per year and water scarcity as less than 1000 cubic meters per person per year (Aijaz & Akhter, 2020). Data presented before the National Assembly of Pakistan to the Assembly shows that the population of the country has grown by approximately 40 million people between 2017 and 2023 and that annual per capita water availability in the country has decreased by 154 cubic meters during that time. With projections of reaching around 288 million by 2030, the country's per capita water availability could further fall to 795 meters per year, which is below the international water scarcity threshold (Desk Web, 2025). Efficient water infrastructure and low storage capacities exacerbate the strain on the water system due to population growth. The water inflow into the major reservoirs of Pakistan can be stored in a fraction of the year which renders the system highly susceptible to droughts and irregular rainfall.

The number of new vehicles on roads is in the millions and congestion is becoming a chronic situation with little control. Pakistan's booming population growth is eroding not just resources but the very social fabric, corroding civic values and weakening public spheres that once held communities together (Siddiqi, 2025). To

conclude, the ever rising population of Pakistan is decreasing the per capita availability of water, is putting pressure on scarce water resources and is worsening the water management issues in Pakistan. International development evaluations have pointed out the impact of population growth on water resources stress in Pakistan along with other factors like climate change and inadequate management. Many parts of the country are already over-extracting groundwater which feeds their drinking and irrigation water supplies, resulting in declining water levels and long term depletion. Ahsan Iqbal highlighted the demographic challenge, pointing out that Pakistan is currently the fifth most populous country in the world, with 80% of the population under 40 and 66% under 30. "These figures are alarming," he said, emphasizing that the federal and provincial governments must collaborate to address the escalating crisis. "Everything depends on the size of the family," he said. With 80% of the population under 40 and 66% under 30, Pakistan is currently the fifth most populous country in the world, he said, highlighting the demographic crisis (Iqbal, 2025). Furthermore, rapid urbanization coupled with population growth is also contributing to high urban water Demand, particularly in big cities such as Karachi and Lahore where water distribution systems are ageing and leaking.

Competition Over Water Resources

Water competition occurs when the demand for water is greater than the supply, resulting in competition between water users including provinces, agricultural and urban water users, industries and ecosystems. The above findings are given as an indication that; the biggest problem is the sustainable development of Region in the future. Therefore, some suggestions are put forward to enhance the healthy development of the region effectively from the aspect of reducing the water footprint of crops and energy crops (Gupta & Ebrahim, 2017). Based on the outlook of reducing the need of energy and crop water footprint, suggestions are proposed for ensuring a healthy development of the region. Upstream water abstraction (via dams, barrages and irrigation canals) may yield greater control to the upstream water users but may reduce flows through to downstream water users. Groundwater provides drinking water for more than two billion people worldwide, and roughly 70 per cent of withdrawals

are used for agriculture (Vision of Humanity, 2025). Water is the key element of life in all ancient cultures as agriculture is the fundamental occupation. There is also intra-sector competition. The challenges brought on by climate change are making the conflict between Pakistan and India over the Indus River Basin more urgent (Bhatti et al., 2026). The agricultural sector uses the most water resources, with only a small amount of water available for the growing urban population and industry.

The increasing use of water for urban expansion by urban water supply providers has led to conflicts between the rural farmers and the urban users, as water is being diverted from the agricultural canals or groundwater. Asia is at the epicenter of global water problems, including crises and security concerns, because its water productivity and efficiency are the lowest in the world. Pakistan, a South Asian nation that has struggled in nearly every area since gaining independence, is hardly an exception (Imran, 2022). The increasing use of water for urban expansion by urban water supply providers has led to conflicts between the rural farmers and the urban users, as water is being diverted from the agricultural canals or groundwater. Asia is at the epicenter of global water problems, including crises and security concerns, because its water productivity and efficiency are the lowest in the world. Pakistan, a South Asian nation that has struggled in nearly every area since gaining independence, is hardly an exception.

Livelihood and Food Security Challenges

Shared structural constraints such as rapid population growth, climate variability, water stress and agrarian dependence affect both livelihood and food security in Pakistan and India, and the socio-economic and policy contexts are also different. 22.1 million hectares of the nation's 79.6 million hectares of cultivated land are supported by IBIS, the largest contiguous canal irrigation system in the world, of which nearly 80% is irrigated; however, this system depends on transboundary waters to the extent of more than 77% (Munir et al., 2021). Agriculture plays a significant role in the livelihoods and food security of a large share of the population in both countries, directly or indirectly, and so any impact on the natural resources and rural economies. However, transboundary flows account for more than 77% of this system. Over 64% of the

country's population, or 132.2 million people, reside in rural areas and work in agriculture, either on or off farms (Munir et al., 2021). The reasons of food insecurity in Pakistan are less agricultural production, weak political arrangements and corruption. Weather extremes have impacted livelihoods and household food security. This has been particularly true in some areas of Baluchistan and Sindh provinces (Ashraf, 2018). Population pressure, poor irrigation management, climate change and variability of upstream water sources have led to water scarcity, which has lowered agricultural productivity. The outcome shows that Pakistan and its current growth will go food insecure by 2030. The Human Development Report published in 2023, took the public records of Pakistan's multidimensional poverty index of the years 2017 to 2018, and estimated that 38% of the population from the year is 2021 to 2022 has been classified as below the poverty line while 13% is in the danger zone of crossing into poverty (Fatima, 2024). Thus, prioritizing food security could significantly contribute to enhancing the security condition in Pakistan.

Pakistan is predominantly an agrarian nation with an agricultural sector that serves as a major source of economic activity, foreign exchange earnings, and the means of subsistence for the majority of the population. The Indus Basin Irrigation System (IBIS), the largest contiguous canal irrigation system in the world, supports 22.1 million hectares of the country's 79.6 million hectares of cultivated land, of which nearly 80% is irrigated; however, this system depends on transboundary waters to the tune of more than 77%. Over 64% of the population, or 132.2 million individuals living in rural areas, work in agriculture either on or off the land. However, transboundary flows account for more than 77% of this system (Baig, 2025). Unpredictable monsoons, droughts, and heat waves are at risk to farm incomes and rural jobs. Although the country has food surpluses, marginal farmers, landless farmers and informal workers struggle to attain stable livelihoods, resulting in malnutrition and food insecurity. Informal livelihoods and access to affordable and nutritious food in cities are also further threatened by urbanization and rural to urban migration. Food scarcity has become a critical challenge for developing countries, particularly Pakistan, a nation with the fifth-largest population and an agriculture-based economy (Iftikhar, 2025).

There is a vicious cycle of livelihood insecurity and food insecurity in both countries. In conclusion, the persistent experienced food and livelihood insecurity in Pakistan and India despite policy interventions and food support programs are attributed to structural inequalities, environmental stress and demographic pressures.

Climate Change and Hydrological Variability

Hydrological variability has been significantly increased by climate change in Pakistan and India, two countries in South Asia which are especially vulnerable to hydrologic systems relying on climate-sensitive river systems, monsoon rains and glacier-fed water sources. According to studies, by the end of the twenty-first century, fresh water resources and agricultural productivity will have significantly decreased, and the average world temperature may rise by 1.4–5.8 °C (Misra, 2014). Under the same Representative Concentration Pathway (RCP) conditions, the vulnerability of Pakistan to climate change is likely to grow. The changes in temperature, precipitation and more extreme weather events are breaking the current hydrological cycles, impacts on water security are particularly acute in the downstream areas. The recent monsoon season has led to widespread devastating flooding that claimed 15 per cent of Pakistan's population, following extreme heat waves in the country followed by worst rains and flooding in its history (Somani, 2023). But in the long term, ongoing glacier melting will have long-term adverse impacts on water supply for downstream provinces like Sindh and southern Punjab. Also, the variability in monsoon rainfall has resulted in a high frequency of droughts and flood events, making water sources less dependable for irrigation, hydropower generation, and consumption. However, such impacts are expected to increase as the climate change related events, environmental deterioration, and air pollution are projected to lead to a decrease in Pakistan's GDP by 18-20% by 2050 (Baron & Asad, 2023). The glacier melt has started to occur at a faster rate with the rise of temperatures which has led to increased river flows and consequently greater flood risks in northern regions.

Pakistan is highly susceptible towards the harmful effects of climate change. The impact of climate change in India has also affected the hydrological cycles of key river basins like the Ganges,

Brahmaputra and Godavari (Verner et al., 2025). The occurrence of flood and drought have been enhanced due to the erratic monsoon behavior of delayed onset, spatial variation and extreme short duration rainfall. Himalayan glacier melt has impacts on the northern river systems changing the flow regime of these rivers and making the uncertainty faced by the river users more complex. Concurrently, the warming has been accompanied by higher evapotranspiration rates, thus lowering the effective availability of water for already water stressed areas like Rajasthan, Maharashtra and southern India. Climatic hydrological variability has increased water stress in downstream regions of both countries with the highest population density, agriculture need and urban water demand (Eckstein et al., 2017). Furthermore, water insecurity has intensified further due to the damage that extreme events like floods cause to reservoirs, canals and water supply systems and due to threat of groundwater depletion in the event of prolonged droughts. The devastating floods of 2022 brought global warming to Pakistan's attention, and it is now urgent to take action and adapt to a changing climate. The world, including Pakistan, is increasingly concerned about climate change. The nation's attention was drawn to global warming by the devastating floods of 2022, and there is a pressing need to take action and adjust to a changing environment (Khan, 2024). In summary, climate change has altered the hydro-dynamic variability in Pakistan and India from seasonal to structural water governance crisis, which is jeopardizing sustainable development, food security and millions of people that rely on stable hydro-dynamic of rivers.

Impacts on the Indus River System

The Indus River System (IRS) is one of the most climate-sensitive river basins in the world, it is heavily reliant on glacier and snowmelt from the Hindu Kush–Karakoram–Himalayan (HKH) region and on monsoon rainfall. More than 40% of the Indian population could potentially face water scarcity for safe drinking water by 2030. The impact of climate change on India and Pakistan will be far reaching and have profound implications on the entire South Asian region. From 1990 to 2008, more than 750 million people were impacted by disasters with little short of 230,000 deaths (Barrech et al., 2023). One of the most significant effects of climate change on the Indus River System is accelerated glacier and snowmelt. Rising

temperatures are causing glaciers in the upper Indus Basin to melt more quickly. The physical changes of northern Pakistan due to glacial lake outburst floods (GLOFs) have increased in frequency and pose risks to infrastructure, settlements and water management systems. Changes in precipitation patterns brought on by climate change speed up glacier retreat and increase the frequency of droughts and floods in the basin. This study's goal was to examine the water quality in the Indus basin and evaluate how climate change affects the hydrological cycle, glacier dynamics, and water quality (Khizar et al., 2025). In the longer term, however, glacier retreat is likely to diminish melt water supply particularly in dry seasons reducing the sustainability of river flows. In addition, the hydrological changes within Indus Basin have become more variable due to climate change.

The irregular rainfall, delayed onset of monsoons and heavy rainfall have led to more frequent extreme events, including heavy rain and droughts. Major floods such as 2010 and 2022 have caused damages to agricultural land, irrigation facilities and reservoirs; while the droughts have affected the water supply for irrigation and domestic purposes in downstream provinces like Sindh and southern Punjab. Water losses from reservoirs, canals, and soils have accelerated and added to the already strained irrigation system, the world's largest continuous irrigation system (Siyal & Hashmi, 2018). Climate change brings about changes in precipitation, glacier melting, and more floods and droughts in the basin. This has led to water use efficiencies being adversely affected and to increased competition between water use in agriculture, industries, and domestic applications. Seasonal flow regime of Indus is also impacted by climate change. The natural flow regimes are growing increasingly variable and unpredictable, making operations of reservoirs, crop planning and hydropower generation more challenging (Ahmad, 2023). Lower flows during dry seasons are a great concern for downstream ecosystems like the Indus Delta, where less freshwater supply has led to intrusion of seawater, deterioration in the mangrove forests, and limitations in fisheries-based livelihoods. In general, the Indus river system has become a more unpredictable and sensitive water system due to climate change (Ahmed, 2019). Long-term water security, food production and socioeconomic stability in the downstream regions

of Pakistan are under threat due to combined effect of glacier retreat, changing precipitation patterns, higher frequency of extreme events, and higher water losses.

Conclusion

The study determined that Water security has now turned into one of the topmost non-traditional security challenges facing Pakistan, especially in the downstream of Indus River Basin. This research has shown that the water crisis that the nation is faced with is not due to any single factor but the outcome of the rapid rate of population increase, rapid industrialization, climate change, poor institutional governance/system and poor practices of water management. Simultaneously, informal urbanization has aggravated the extraction of groundwater, water contamination, strain on already insufficient water supply and sanitation facilities. These challenges have been further compounded by climate changes that have affected the hydrological cycle by retreating glaciers, unpredictable monsoon rainfall patterns, extended drought, frequent floods, heightened temperatures, and rising sea level, which have lowered the amount and quality of fresh water supply down the river to the communities. It was concluded that water security in the long term should be carried by a holistic and integrated policy and no single interventions. Sustainable water management involves reinforcing the Integrated Water Resources Management (IWRM), enhancing institutional coordination, increasing water storage, modernizing irrigation systems, enhancing water conservation, and demand-side management, safeguarding groundwater resources, and investing in climate resilient infrastructure. Moreover, proper execution of the National Water Policy, fair distribution of water between the provinces, enhanced cross boundary cooperation between the states through the Indus Waters Treaty, and sustainable population planning must prioritize to minimize water insecurity in the future. Otherwise, the compounding effects of population increase, urban sprawl, and climatic change will remain a significant part of the challenges to the environmental sustainability, socioeconomic progress, and national security of Pakistan unless a coherent and adequate response is taken in time. Thus, evidence-based policies and governance approaches at the local, provincial, national, and transboundary governance are critical towards

achieving resilient and sustainable water security in current and future generations.

Conflict of Interest

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